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Development and validation of a novel monitoring system for batch flocculant solids settling process

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Abstract

Secondary sedimentation is the main hydraulic bottleneck of effective pollution control WWTP under wet-weather flow conditions. Therefore, online monitoring tools are required for control and optimization of the settling process under dynamic conditions. In this work we propose a novel monitoring system able to monitor batch settling tests by tracking the sludge blanket height and solid concentration along the column in the range of 1 to 8 g L^{-1}. The system could be efficiently applied to monitor the batch settling tests of several full scale treatment plants run under different operational conditions.

Keywords: sensor development; image analysis; sedimentation; model identification

INTRODUCTION

Activated sludge secondary sedimentation is, by far, the most widely used solid-liquid separation unit process operation in wastewater treatment plants (WWTP). It is also considered as the main hydraulic bottleneck of effective pollution control in urban areas under wet-weather flow conditions. Secondary sedimentation of activated sludge can be heavily impacted by filamentous organisms. Polymer is usually overdosed to minimize the impact of filaments on settling properties. One way to overcome such operational inefficiencies is to monitor the sedimentation process using sensor technology. However, up to date not reliable and simple methods exist to monitor the settling process. Sophisticated and commercially unviable methods were developed in the past years, which rely in techniques such as the use of radiotracers (De Clercq et al., 2005) or ultrasonic transducers (Locatelli et al., 2015). Whilst these techniques provide a good insight of the settling process, they are rather expensive or not suitable for online process monitoring at the WWTP. As a cost-effective alternative, Ramin et al. (2014) proposed to implement a TSS sensor at the bottom of a settling column, so both SBH and bottom TSS can be monitored in a batch test. This approach, however, can also be limited in terms of information required for reliable model identification. The goal of this contribution is to develop a novel sensor that, based on image analysis, is able to estimate the sludge blanket height (SBH) and TSS concentration profile in the settling column. The sensor data acquisitioned were assessed in terms of parameter identification using selected state-of-the-art settling velocity models. The identified parameters can serve as useful controlled variables in WWTP under hydraulic and/or microbial (e.g., filamentous bulking) shock conditions.

MATERIALS AND METHODS

Sampled wastewater treatment plants

A total of 10 WWTPs from Denmark and Sweden were sampled in the summer 2015 and winter-spring 2016. Sampled WWTPs comprise conventional activated sludge systems (e.g. Lynetten or

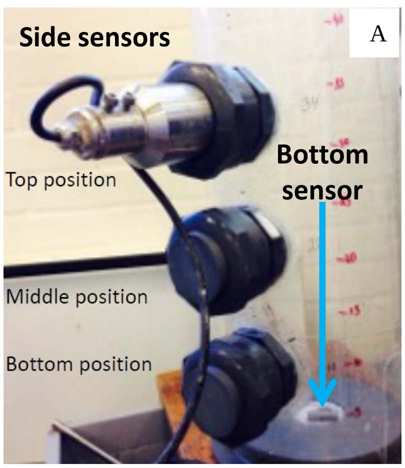
Lundtofte), high rate activated sludge systems (e.g. Ellinge or Sjölunda) or systems where filamentous bulking was controlled via polymer or chlorine addition (e.g. Avedøre or Fredericia).

Sensor prototype 1

First sensor prototype consisted on the device described by Ramin et al. (2014) but modified as shown in Fig. 1a, i.e. TSS sensors were installed at different heights (0.1, 0.2, 0.3 m from bottom, corresponding to layer number 32, 42, 52 in a simulation model of 60 layers) in the side wall, in addition to the one in the bottom (TSS_{bott}) of the settling column. Settleability of the sludge sampled in summer was monitored with this prototype. The aim of this test was to identify how many data series corresponding to concentrations over time at different heights in the column are needed to for reliable parameter identification.

Sensor prototype 2

Second sensor prototype consisted of the same settling column (Fig. 1b). However, TSS and SBH were monitored with an industrial video camera with a cmos sensor (2000 x 2500 pixels) and USB interface. The camera was configured with a set exposure and zero gain. 11 vertical pixel columns, corresponding to a width of approximately 4mm, were averaged to give a horizontal spatial averaging and 3 video frames were averaged to give a temporal averaging. The vertical resolution was approximately 0.35mm. TSS values were calculated as a function of the averaged pixel intensities. SBH values were calculated based on the point at which the pixel intensities saturated (became overexposed at pixel grey-scale value 255) which is when the diffuser is visible through the column immediately above the sludge blanket.



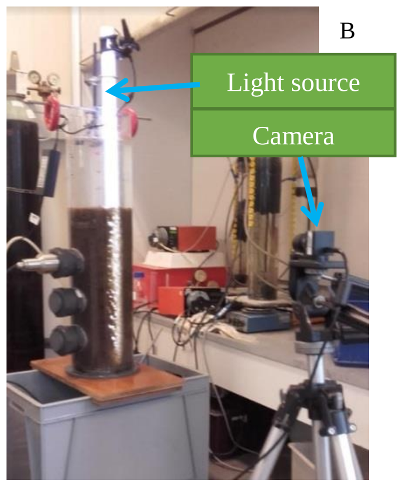


Figure 1. a) Settling sensor setup (prototype 1), including the infrared TSS probe in the upper position; b) Settling sensor setup (prototype 2), including the camera and the visible light source.

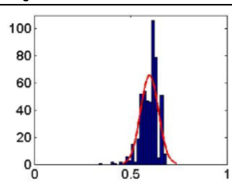
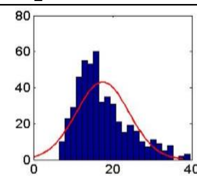
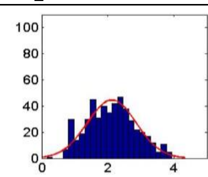
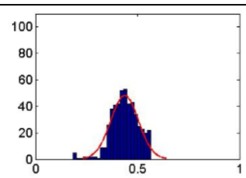
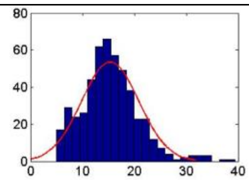
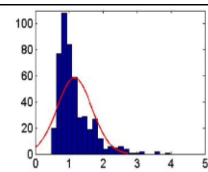
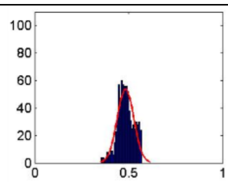
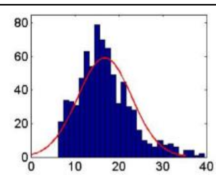
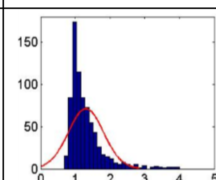
Model calibration methodology

Data obtained using sludge samples taken in the different WWTPs were used to calibrate the hindered-transient-compression (HTC) settling velocity model (Ramin et al., 2014) using the latin hypercube sampling-based simplex method, LHSS (Wágner et al., 2016). The dataset from summer 2015 in Fredericia was used for model calibration of the hindered, transcient and compression (HTC) model by Ramin et al. (2014).

RESULTS AND DISCUSSION

In a first step, we used sensor prototype 1 to assess the improvement on parameter identifiability compared to the study by Ramin et al. (2014). Based on the identifiability analysis prototype 1 (i.e., Exp.2, Table 1) has the potential to improve parameter identifiability compared to the test by Ramin et al. (2014; Exp.1 Table1). However, monitoring TSS at different levels in the column (Exp.3 Table1) seems to give limited imporvement compared to Exp.1 (Table 1). Simulation results are shown in Fig. 2.

Table 1. Identifiability analysis – histograms and correlation matrix. Parameter correlation shaded.

<table>
<tr><th></th><th>r_t</th><th>C_1</th><th>C_2</th><th>Correlation Matrix</th></tr>
<tr><td><u>Exp. 1 (Fredericia)</u>
SBH and bottom TSS (Ramin et al., 2014)</td><td></td><td></td><td></td><td><table><tr><td></td><td>r_t</td><td>C_1</td><td>C_2</td></tr><tr><td>r_t</td><td>1</td><td></td><td></td></tr><tr><td>C_1</td><td>0.32</td><td>1</td><td></td></tr><tr><td>C_2</td><td>0.38</td><td>-0.57</td><td>1</td></tr></table>r_t=0.60±0.05
C_1=17.48±6.69
C_2=2.12±0.74</td></tr>
<tr><td><u>Exp. 2 (Fredericia)</u>
SBH, bottom TSS and TSS in layer 42</td><td></td><td></td><td></td><td><table><tr><td></td><td>r_t</td><td>C_1</td><td>C_2</td></tr><tr><td>r_t</td><td>1</td><td></td><td></td></tr><tr><td>C_1</td><td>0.44</td><td>1</td><td></td></tr><tr><td>C_2</td><td>0.33</td><td>-0.27</td><td>1</td></tr></table>r_t=0.44±0.07
C_1=15.36±5.51
C_2=1.15±0.52</td></tr>
<tr><td><u>Exp. 3 (Fredericia)</u>
SBH, bottom TSS and TSS in layers 32&42&52</td><td></td><td></td><td></td><td><table><tr><td></td><td>r_t</td><td>C_1</td><td>C_2</td></tr><tr><td>r_t</td><td>1</td><td></td><td></td></tr><tr><td>C_1</td><td>0.65</td><td>1</td><td></td></tr><tr><td>C_2</td><td>0.45</td><td>-0.038</td><td>1</td></tr></table>r_t=0.48±0.05
C_1=16.83±6.14
C_2=1.31±0.51</td></tr>
</table>

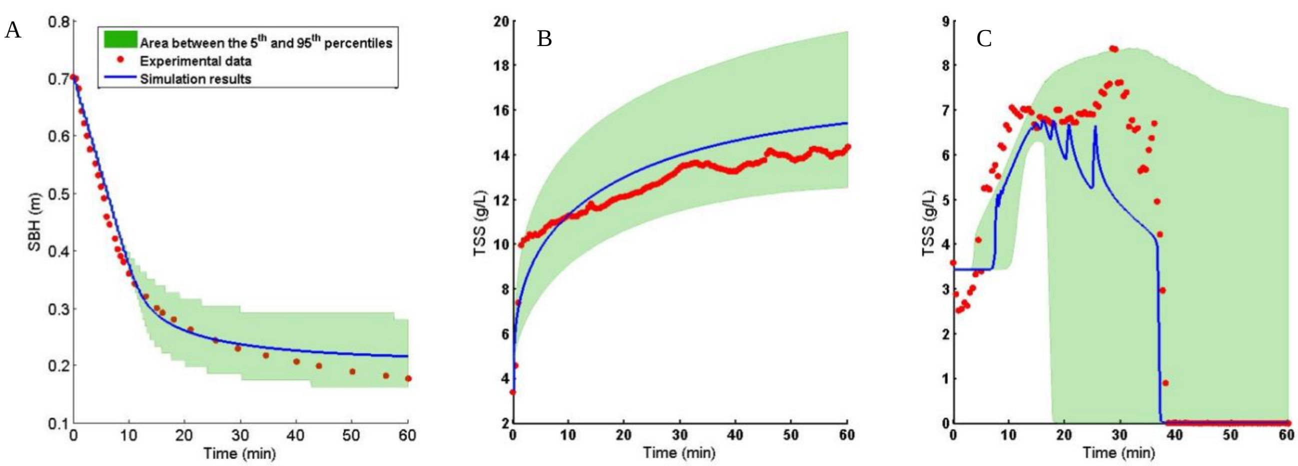


Figure 2. a) Experimental (Fredericia WWTP) and simulation results (with uncertainty range) – SBH; b) TSS at column bottom; c) TSS in side-wall (layer 42). TSS concentration data measured using the infrared sensors (prototype 1).

In prototype 2, we devoped a second sensor able to fully automatize the monitorization of the settling test. On the one hand, similar to existing image analysis based technologies (Mancell-Egala et al., 2016; Derlon, et al., 2017), the camera is able to track the SBH over time. Therefore, operators do not need to manually record the SBH over time (see, e.g., Ramin et al. 2014). On the other hand, the sensor is able to track TSS concentrations in the range of 1-8 g L^{-1}. Therefore, the sensor is able to track concentrations at different height of the column. The levels at which the camera-based sensor is set to monitor TSS concentration should be carefully located pending on the initial concentration of the settling test – higher initial concentrations will yield to concentrations above 8 g L^{-1}, which cannot be quantified by the sensor. However, this limitation barely has an impact on identifiability, as based on Table 1 a data series corresponding to a specific column height is sufficient to improve parameter identifiability. Fig. 3 shows the TSS prediction by the camera based sensor compared to conventional infrared probe for different WWTP.

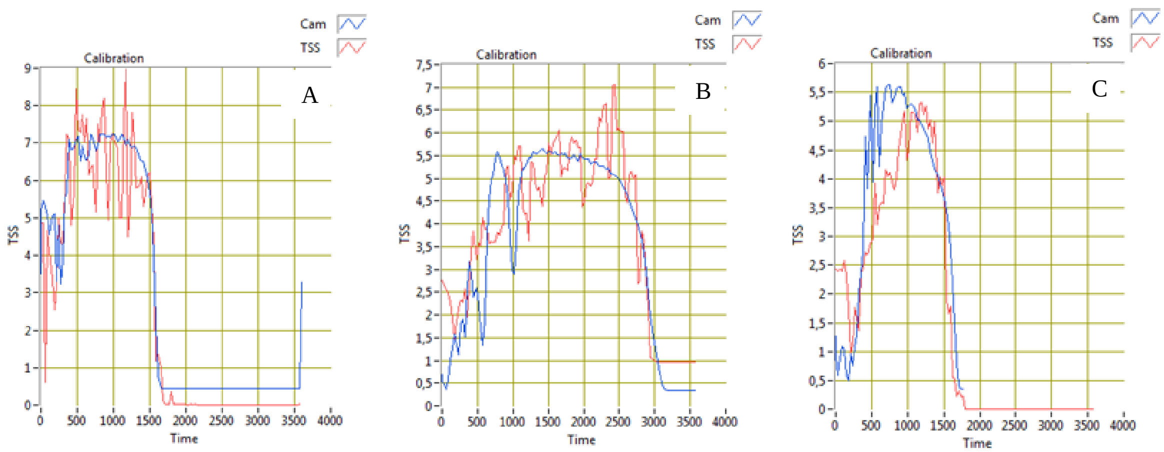


Figure 3. TSS predicted by the infrared sensor (prototype 1 – red) vs TSS predicted by camera based sensor (prototype 2 – blue) at layer 42 for a) Fredericia; b) Damhusåen; and c) Sjölunda.

This work offers a proof of concept for a novel sensor to monitor batch settling processes offering datasets suitable for parameter identification. The setup is comparably simpler than other existing technologies (e.g., DeClerq et al. 2005), thus making its implementation feasible in full scale WWTP.

Acknowledgement

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